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ABSTRACT -- Distance sampling is a method of estimating population abundance and density used by wildlife biologists for several species because of its advantages relative to other techniques. However, few wildlife biologists have used distance sampling to estimate abundance of white-tailed deer (*Odocoileus virginianus*). We describe a distance sampling technique used to estimate pre-hunt and post-hunt population densities of deer in Watonwan County, Minnesota. Estimates of white-tailed deer density were compared between distance sampling versus population modeling, and costs for distance sampling versus aerial surveys were determined. We drove 2,704 km during 24 spotlight surveys conducted from 21 October to 28 December 2004. We observed 537 white-tailed deer during the pre-hunt period and 620 deer during the post-hunt period. Estimates of white-tailed deer density obtained via distance sampling were more than three times larger than estimates derived by population modeling. Costs for aerial surveys would have been four times greater than costs for distance sampling surveys. We concluded that wildlife biologists should consider implementing distance sampling for estimating deer density because of the advantages and lower costs of distance sampling relative to other techniques.

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Wildlife biologists need reliable estimates of white-tailed deer (*Odocoileus virginianus*) density to facilitate management decisions. Several field-based techniques exist for estimating densities of white-tailed deer, such as aerial surveys (Stoll et al. 1991, Nielsen et al. 1997b, Potvin et al. 2005), mark-recapture or mark-resight analysis (McCullough and Hirth 1988, Nielsen et al. 1997a, Lopez et al. 2004), and thermal infrared surveys (Belant et al. 2000, Haroldson et al. 2003). Some techniques, especially aerial surveys, have been used by state wildlife agencies for decades to estimate population density of white-tailed deer (Osborn et al. 2003). However, survey methods frequently need updating as more advantageous alternatives become available.

Distance sampling is a technique that shows considerable promise for estimating density and abundance of wildlife. Briefly, distance sampling is based on the concept that not all animals will be observed during surveys due to visibility bias caused by visual impediments and observer error (Buckland et al. 2004); these problems plague other survey methods (Beringer et al. 1998, Haroldson et al. 2003). In distance sampling, a detection function is generated that estimates how detection of objects changes with increasing distance from the observer. The detection function is then used to estimate the area sampled, and density is computed as the number of animals observed divided by the area sampled (Buckland et al. 2004).

Distance sampling (formerly line transect sampling) is not a new technique for estimating population abundance and density (Burnham et al. 1980, Gogan et al. 1986). However, only recently has a rigorous theoretical basis been formulated and tested for estimating the abundance of wildlife populations by using distance sampling (Buckland et al. 1993, Buckland et al. 2001, Buckland et al. 2004). Several publications have described and tested the use of distance sampling for wildlife (Thompson et al. 1998, Focardi et al. 2002, Swann et al. 2002, Norvell et al. 2003, Ruette et al. 2003). In fact, program DISTANCE 4.0 (Thomas et al. 2002) has been downloaded by more than 6,200 users during the last three years (http://www.ruwpa.st-and.ac.uk/distance/distanceusers.html).

Despite the apparent advantages and widespread use of distance sampling methods, there is a paucity of information regarding the use of distance sampling to estimate population density of white-tailed deer. Such information would be useful for state wildlife agencies that are charged with managing deer populations. For example, the Minnesota Department of Natural Resources uses population modeling (Grund and Woolf 2004) and aerial surveys (Osborn et al. 2003) to estimate white-tailed deer density. However, aerial survey costs are problematic and population models are difficult to calibrate, necessitating the consideration of other methods of estimating white-tailed deer populations. Our objectives were to 1) describe a distance sampling survey to estimate population density of white-tailed deer in Watonwan County, Minnesota; 2) compare estimates of white-tailed deer density derived from distance sampling versus population modeling; and 3) compare survey costs for distance sampling versus aerial surveys.

STUDY AREA and METHODS

We conducted distance sampling surveys for white-tailed deer in Watonwan County, Minnesota, which is located in the south-central portion of the state. Watonwan County is dominated by cropland (92%), primarily corn (*Zea mays*) and soybeans (*Glycine max*), with relatively little grassland, forest, and marshland cover (Minnesota Gap Land Cover 2000). The 30 year average temperature recorded at the Minneapolis International Airport, which is approximately 125 km northeast of Watonwan County, ranges from -8.9°C in winter to 21.6°C in summer. Average precipitation in the winter and summer is 122 cm (primarily snowfall) and 28.4 cm (rainfall), respectively (http://www.noaa.gov). Watonwan County is 314 m above sea level and changes in elevation are relatively minor.

We conducted 24 road-based distance sampling surveys from 21 October to 28 December 2004. Twelve surveys were conducted prior to the regular firearms white-tailed deer season (21 October - 4 November) and 12 surveys were conducted after the hunting season (15 November - 28 December). Although we recognize that distance sampling methods prefer randomly placed transects (Buckland et al. 2001), this was not logistically possible with driving surveys (i.e., we were constrained by road placement on the landscape). We therefore selected routes within Watonwan County that have been used traditionally by the Minnesota Department of Natural Resources for other wildlife surveys; these roads have been used as such because they accurately represent wildlife habitat available in Watonwan County. We do not think our road-based surveys were biased because 1) we were traveling through representative habitat, 2) white-tailed deer distribution did not seem to be affected by road presence, and 3) white-tailed deer behavior was not affected by the presence of pickups on roads. Other assumptions of distance sampling include objects on transects always are detected and distances are measured accurately (Buckland et al. 2001). Although we did not experimentally test these assumptions, they were largely met as we carefully watched for and counted white-tailed deer directly on the road and used laser rangefinders to measure distances accurately.

Surveys were conducted from 1700 to 2300 hr. During surveys, two observers searched for white-tailed deer by using hand-held spotlights while a pickup truck traveled two east-west transects approximately 40 km in length, at speeds less than 32 km/hr. We varied our starting point every night to reduce the probability of observing the same white-tailed deer in the same places at corresponding times of the survey. Observers determined distance to centers of white-tailed deer clusters (i.e., groups) with a laser range finder and determined angles to centers of clusters with a prismatic compass. Clusters were separated by using nearest neighbor criterion (LaGory 1986) and location of white-tailed deer and their behavior. In general, a group of white-tailed deer behaving similarly in close proximity to each other was considered a cluster. We also measured distances from observers to white-tailed deer clusters and noted whether animals were observed in cropland, forest, or grassland cover types. A two-way ANOVA and post-hoc Tukey tests were used to test survey period effects, cover type effects, and their interactions on distance-to-white-tailed deer and cluster size data. We used SAS (SAS Institute 1999) for all statistical analysis ($P = 0.05$ throughout).

We used the program DISTANCE 4.0 (Thomas et al. 2002) to estimate population densities of white-tailed deer for both pre-hunt and post-hunt periods. We analyzed data as suggested by Buckland et al. (1993:139-140), by 1) examining initial histograms of sighting distance versus count frequency data to determine appropriate truncation of outliers to improve estimation of the detection function, 2) analyzing candidate data sets and choosing the best-fit model of the detection function, 3) pooling sighting data categories to improve model fit, and 4) assessing cluster size bias. Half-normal cosine functions were performed in Distance 4.0 and the best model was chosen based upon minimum Akaike Information Criterion values.

Distance sampling estimates were compared to output derived from a population model used by the Minnesota Department of Natural Resources for two corresponding permit areas in Watonwan County. The population model is an accounting procedure that subtracts losses, adds gains, and keeps a running total of the number of animals alive in various sex-age classes during successive periods of the annual cycle. The white-tailed deer population is partitioned into four sex-age classes (i.e., fawns, adults, males, and females), and the 12 month year is divided into four periods representing various biological events in a white-tailed deer's life (i.e., hunting season, winter, reproduction, and summer). Grund and Woolf (2004) provide a more detailed description of the structure and function of this model.

We did not actually perform aerial surveys as part of our project, but compared costs between previously flown aerial surveys and distance sampling conducted during our study. We recorded all costs (i.e., personnel, mileage, and gas) associated with distance sampling and costs of conducting aerial surveys over the exact same study area (i.e., flying helicopter over our road transects). Costs for distance sampling were calculated based on time associated with observing 60 clusters of white-tailed deer for each survey period, which is the minimum number necessary for an accurate estimate of density (Buckland et al.

2001). Both survey methods required two observers at \$10/hr. Aerial survey costs were based on previous helicopter quadrat surveys (Siniff and Skoog 1964, Evans et al. 1966, Bartmann et al. 1986) conducted by the Minnesota Department of Natural Resources (Osborn et al. 2003). Unfortunately, the permit areas upon which our distance sampling surveys were conducted were not flown during 2004.

RESULTS

Mean time spent afield per survey during pre-hunt and post-hunt periods was 4.4 (SD = 0.7) and 3.5 hours (SD = 0.4), respectively. We observed 259 clusters of white-tailed deer (537 individuals) during the pre-hunt period and 214 clusters (620 individuals) during the post-hunt period. Mean cluster size during pre-hunt and post-hunt periods was 2.1 (SE = 0.1) and 2.9 white-tailed deer/cluster (SE = 0.2), respectively. A half-normal key estimator was selected by using DISTANCE 4.0, and the pre-hunt estimate of density was 7.0 white-tailed deer/km^2 (SE = 2.0) and the post-hunt estimate was 5.0 white-tailed deer/km^2 (SE = 2.0), representing a 28% reduction in white-tailed deer density during the harvest period. The 2004 simulation model calculated by the Minnesota Department of Natural Resources resulted in a pre-hunt density of 1.9 white-tailed deer/km^2 and a post-hunt estimate of 1.5 white-tailed deer/km^2, representing a 21% reduction in white-tailed deer density during the harvest period.

There was a simple habitat effect during the post-hunt survey period ($F_{2,463}$ = 12.9, $P < 0.01$); more white-tailed deer ($P < 0.05$) were observed in tallgrass cover during the post-hunt period than in forest or cropland cover (Fig. 1). White-tailed deer were observed in equivalent numbers in all cover types during the pre-hunt period ($F_{2,463}$ = 0.6, $P > 0.05$). Distances from observer to clusters were less ($P < 0.05$) during the pre-hunt period (mean = 128 m, SE = 5) than the post-hunt period (mean = 145 m, SE = 7). During the pre-hunt period, white-tailed deer were observed at greater distances ($P < 0.05$) in cropland cover (mean = 153 m, SE = 6) than in forest cover (mean = 123 m, SE = 11) or tallgrass cover (mean = 108 m, SE = 5; Fig. 2).

The cost of conducting distance sampling was \$1,225. Fifty-eight total hours of labor were required (\$580), and vehicle mileage and gas was \$645. Costs for aerial surveys over the same study area would have been \$4,200: \$700 for lodging, per diem, and 10 hours of pilot and technician labor, and \$3,500 for 10 hours of flight time.

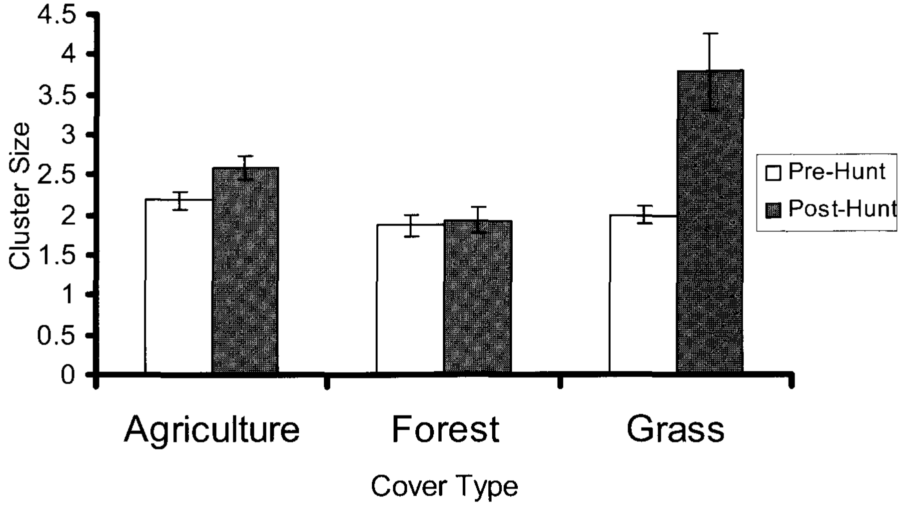

Figure 1. Mean cluster sizes (SE) of white-tailed deer by cover type and survey period, Watonwan County, Minnesota, 21 October to 28 December 2004.

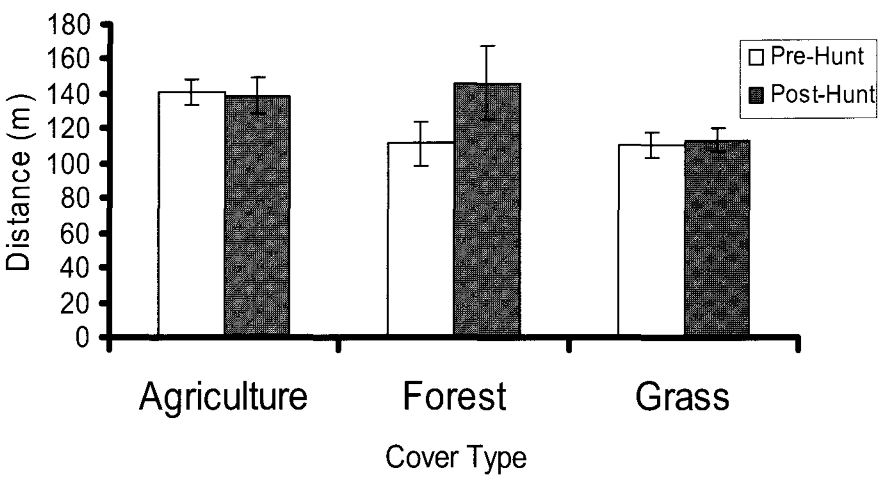

Figure 2. Mean distances (SE) between observers and deer by cover type and survey period, Watonwan County, Minnesota, 21 October to 28 December 2004.

DISCUSSION

Comparisons among methods of estimating population abundance and density are critical for improving biologists' ability to understand and manage wildlife populations (Belant and Seamans 2000, Haroldson et al. 2003). We report considerable differences between estimates of white-tailed deer density obtained from distance sampling versus a population model. Specifically, estimates of white-tailed deer density were more than three times greater for distance sampling than the population model. These findings have considerable implications for wildlife managers. For example, if white-tailed deer density is underestimated, harvest levels might be set too low, which might unwittingly promote white-tailed deer overabundance. We can not be sure which estimator is closer to the true density of white-tailed deer on our study area. However, the well-founded statistical advantages of distance sampling (Buckland et al. 2001) likely make this method relatively accurate. This is especially true given that the population model we used is admittedly imperfect and requires periodic updates with new data (Grund and Woolf 2004).

For both distance sampling and population modeling, post-hunt densities of white-tailed deer were lower than pre-hunt densities, and the relative magnitudes of differences were nearly the same for each estimation method. These reductions in population density are somewhat consistent with studies reporting rate of mortality caused by hunting (Nelson and Mech 1986, DelGuidice et al. 2002). We might have concluded that the population had increased after the hunting season if we just conducted spotlight surveys (537 white-tailed deer observed during pre-hunt and 620 white-tailed deer observed post-hunt). Because of crop harvest and leaf drop we observed more white-tailed deer (n) during the post-hunt period. However, we also sampled a larger area (a) during the post-hunt period due to our ability to see greater distances. Thus, the estimated post-hunt population density (D) was lower than the pre-hunt density even though we observed more white-tailed deer during the post-hunt period ($D = n/a$). This example illustrates how the detection function accounts for items such as crop harvest and other changes in vegetative phenology that might differ seasonally (Buckland et al. 2004).

We recommend wildlife managers consider using distance sampling to estimate population density of white-tailed deer in North America. During the past decade, distance sampling has been used in more than 120 countries worldwide to estimate density and abundance of hundreds of wildlife species (http://www.ruwpa.st-and.ac.uk/distance/distanceusers.html; Anderson et al. 1983, Corn and Conroy 1998, Tomas et al. 2001, Focardi et al. 2002, Perez et al. 2002, Dique et al. 2003, Ruette et al. 2003). Distance sampling contains very low bias (i.e., difference between the estimate and true population size) as determined by several studies that compared distance sampling estimates to known numbers of animals;

these studies commonly report distance sampling estimates within 15% of the true population size (Buckland et al. 1993, Anderson et al. 2001). In addition to this fundamental advantage of distance sampling, we indicated several other reasons why wildlife managers should consider distance sampling surveys for white-tailed deer.

Our study suggested that distance sampling might be a cost-effective alternative to aerial surveys; however, we think more research is warranted to substantiate that conclusion. Aerial surveys are a very popular white-tailed deer survey method (Stoll et al. 1991, Beringer et al. 1998, Potvin et al. 2005) and one used frequently by the Minnesota Department of Natural Resources (Osborne et al. 2003). However, there are several disadvantages to using aerial surveys to estimate population size of white-tailed deer. First, aerial surveys require adequate snow cover (more than 10 cm) uniformly distributed across the landscape during the entire sampling period. This dependence on snow cover restricts use of this method to a very narrow winter period for many portions of the United States. Any patches of soil not covered by snow will hide white-tailed deer; hence, without snow cover, detection rates are only 36 to 75% (DeYoung 1985). Second, visibility of white-tailed deer is made difficult by thick ground cover. Brushy areas or dense conifer stands will conceal white-tailed deer, and even though a plane or helicopter is flying over, white-tailed deer might hide in these areas and not be observed. Third, even with complete snow cover and high deer visibility, aerial survey estimates often underestimate number of white-tailed deer on the ground by more than 20% (Beringer et al. 1998). Hence, the primary problem with aerial surveys is that white-tailed deer will be missed, and frequently the proportion missed is entirely unknown. Furthermore, aircraft might not always be available concomitant with snowfall, which poses an additional problem to the use of aerial surveys.

Distance sampling avoids many of the disadvantages of aerial surveys. First and most importantly, distance sampling allows 60 to 80% of individuals to be missed during surveys and still obtain robust (i.e., unbiased) estimates of the true population size (Buckland et al. 1993). Second, distance sampling surveys can be performed at any time during the year because they are not dependent on adequate snow cover; distance sampling only requires that conditions facilitate accurate vision (i.e., no fog or rain). Third, information on sex and age ratios can be obtained during distance sampling counts. Hence, distance sampling represents a statistically rigorous and tested technique of population estimation that does not rely on the presence of adequate snow.

Our results also suggested a strong financial incentive to use distance sampling relative to aerial surveys, as the latter was four times more costly than the former. Many wildlife agencies still use spotlight surveys, which provide only index data (McCullough 1982). Only minor changes in methodology (i.e., collecting distance and angle data) would be necessary to enhance spotlight estimates from indices to actual population density.

Finally, in addition to white-tailed deer density, additional data can be collected during distance sampling surveys that can lend insight into white-tailed deer ecology. Cluster sizes of white-tailed deer were greater after the hunting season than before, even after white-tailed deer had been removed via harvest. This is likely due to white-tailed deer group size increasing in the winter months (Marchinton and Hirth 1984). Further, more white-tailed deer were observed in tallgrass cover during the post-hunt period than in forest or cropland cover. During the post-hunt period, white-tailed deer were likely feeding on grass, which is a preferred late-fall and early winter food item (Whittaker and Lindzey 2004). Hence, the benefits of distance sampling are not only for estimating density, but also collecting observational data that can be used to understand white-tailed deer social organization or for habitat analyses.

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